One-quarter of the northern hemisphere’s land is permanently frozen or frozen for extended periods. The planet’s warming has been most rapid in the far north, where rising heat simply melts permanently frozen land. Infrastructure of every kind, from buildings, roads, and railways, to pipelines, airports, and power lines come under stress or are damaged when the rate of melting is accelerated. The entire infrastructure of the far north and the world’s coldest zones is affected. Overall, the effect is estimated to accelerate by around 10–20% the rate of wear and tear on all exposed infrastructure in the near term.

### 2010 Effect Today
- **Economic Impact:** 30 billion USD loss per year
- **Affected:** 9% of population
- **Injustice:** 4% of population
- **Priority:** 44% of population
- **MDG Effect:** 4% of population

### 2030 Effect Tomorrow
- **Economic Impact:** 150 billion USD loss per year
- **Affected:** 55% of population
- **Injustice:** 4% of population
- **Priority:** 49% of population
- **MDG Effect:** 3% of population

### Relative Impact

<table>
<thead>
<tr>
<th>Country</th>
<th>2010</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>15,000</td>
<td>75,000</td>
</tr>
<tr>
<td>China</td>
<td>9,250</td>
<td>65,000</td>
</tr>
<tr>
<td>Mongolia</td>
<td>600</td>
<td>4,000</td>
</tr>
<tr>
<td>Canada</td>
<td>1,750</td>
<td>3,500</td>
</tr>
<tr>
<td>Pakistan</td>
<td>400</td>
<td>2,000</td>
</tr>
</tbody>
</table>

### Geopolitical Vulnerability

<table>
<thead>
<tr>
<th>Region</th>
<th>BRIC</th>
<th>SIDSs</th>
<th>LDCs</th>
<th>OECD</th>
<th>G8</th>
<th>G20</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td></td>
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<td></td>
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<tr>
<td>Russia</td>
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<td>Pakistan</td>
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</tbody>
</table>

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<table>
<thead>
<tr>
<th>Economic Cost (2010 PPP non-discounted)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Developing Country Low Emitters</td>
</tr>
</tbody>
</table>

\[ \text{Change in relation to overall global population and/or GDP} \]
Permafrost thawing is one impact of climate change that does not spare some of the world’s most advanced and industrialized countries. In some places rising heat is causing dry lands to degrade into desert. In the coldest parts of the world, the heat is instead causing land to melt and sink, damaging infrastructure as it subsides (Larsen and Goldsmith, 2007). Every conceivable type of infrastructure is at risk as permafrost melts, including buildings, roads, railways, and oil pipelines (Xu et al., 2010; Lin, 2011M; Feng and Liu, 2012). Preserving this infrastructure as growing heat adds to the stress is a major challenge for engineers and a serious cost for local communities (McGuire, 2009). In Alaska, for instance, two-thirds of the state roads budget is spent on permafrost repair alone (Stidger, 2001). In worst case scenarios, it is estimated that extreme permafrost thaw could force the relocation of entire communities (Romanovsky et al., 2010). Permafrost thawing through accelerated infrastructure replacement and repair will impose significant cost burdens on the world’s coldest communities.

**CLIMATE MECHANISM**

As temperatures rise, regions nearer the poles are heating up the fastest (IPCC, 2007). Much of the land within the Arctic Circle is frozen on a permanent basis, or for more than 1–2 years. The permafrost region currently covers about one-quarter of earth’s land area (Nelson et al., 2002); however, it is home to only a fraction of the world’s population (Hoekstra et al., 2010). One-quarter of the land area of the northern hemisphere has a subterranean layer of ice built up under the soil which can melt when temperatures rise (Anisimov, 2009). The warming planet thaws otherwise permanently frozen land, destabilizes it, alters its ecosystem, and compromises the structural integrity of any buildings or infrastructure that have been constructed in these zones (Romanovsky et al., 2010). In this way, climate change is already accelerating the process by which key infrastructure in these areas requires repair or replacement (Larsen and Goldsmith, 2007).

**IMPACTS**

The impact of climate change on infrastructure in affected permafrost zones is estimated globally at 30 billion dollars a year in 2010. With the expected increase in temperatures through to 2030, losses associated with permafrost thawing are estimated to grow as a share of global GDP, amounting to approximately 150 billion dollars a year. Countries worst affected include the US (because of Alaska), Canada, China (because of Tibet), Mongolia, Russia, and a number of Central Asian states (because of the Himalayas). As climate change intensifies, the same group of countries continues to be affected. The largest total losses are incurred in Russia, China, Mongolia, and Canada. Losses for Russia and China are currently estimated at around 20 and 10 billion dollars respectively, and should grow to over 60 billion dollars each year by 2030. Mongolia, Kyrgyzstan, and Bhutan are estimated to suffer the most severe effects as a share of GDP, with Mongolia and Kyrgyzstan’s losses at over 4% of GDP by 2030, and Bhutan’s in excess of 1% of GDP. Some 10 million people are estimated to be affected by the impact of climate change on permafrost globally, a number that will more than double to nearly 25 million by 2030.

**THE BROADER CONTEXT**

Dealing with some degree of oscillation in permanently frozen land in the coldest zones of the planet is normal (Wei et al., 2009). It is the acceleration in these processes that incurs additional costs as temperatures rise. While the northernmost or coldest regions of the planet are sparsely inhabited, oil and gas exploitation has grown in permafrost regions in and around the Arctic Circle. Planned or constructed high value infrastructure in these regions will face growing risks (Pavlenko and Glukhareva, 2010). The same is true for the multi-billion dollar China-Tibet railway, built over partially unstable land across the Tibetan ranges and plateaux (Yang and Zhu, 2011).

**VULNERABILITIES AND WIDER OUTCOMES**

Governments and governments maintaining expensive public infrastructure in lower-middle income countries, such as Kyrgyzstan in Central Asia, will face a major development challenge in tackling accelerated infrastructure erosion. There is a lack of clarity on the extent to which insurance
policies are valid for permafrost erosion damage (Mills, 2005; Williams, 2011). Insurance coverage is growing, as incomes of developing countries expand, suggesting that for many of the worst affected areas, including Tibet, Mongolia, and Kyrgyzstan, a lack of insurance will heighten the impact of these changes (Kharas, 2010). Permanently frozen land also stores around half of the potential soil-derived emissions of greenhouse gases (GHGs), mostly in the form of methane, a highly potent GHG. As such, there is a mounting concern that, as they thaw, permafrost regions could become a major unmanageable driver of global climate change (Tarnocai et al., 2009).

RESPONSES

Adaptation to the thawing of permafrost is a challenge. Future planning might make non-essential infrastructure projects in transition zones less of a priority. For all existing infrastructure, there is a predictable accelerated depreciation and replacement cost that must be faced (Larsen and Goldsmith, 2007). Unlike sea-level rise, changes are likely to come faster, and no wall can prevent the retreat of frozen land which, as it thaws, will decimate any built infrastructure in affected areas. However, for certain types of infrastructure, such as pipelines or railways, measures can be taken to mitigate the extent of destabilising effects, especially when designing new infrastructure (Xu et al., 2010; Wei et al., 2009). Public resources may be considered, for instance, to subsidise or back insurance schemes which allow risk to be managed in a more long-term framework, buffering communities from abrupt losses and enhancing the resilience of highly exposed groups (Verheyen, 2005). In worst cases, community relocation may be necessary (Romanovsky, 2010).

THE INDICATOR

The indicator is understood to be moderately robust. This is because clarity on the climate signal in one of the fastest warming regions of the world is pronounced, and the IPCC’s stance on the possibility of extensive damage stemming from permafrost erosion is firm (IPCC, 2007). However, permafrost damage is for now a niche research area at best, and the indicator’s robustness is compromised by being based on only one study and model from Alaska (Larsen and Goldsmith, 2007). Further uncertainties relate to the extrapolation of the damage estimations through income (GDP) metrics and population-weighted adjustments in order to simulate the damage effects in the other countries. Assumptions were also made by proxy for non-public infrastructure based on capital values of private infrastructure at risk, which could be an area for further improvement. Given the potential scale of the damage, the topic remains a clear research priority for additional enquiry in all respects.
CLIMATE VULNERABILITY

Acute | Severe | High | Moderate | Low

Limited | Partial | Considerable

Vulnerability measure: comparative losses as a share of GDP in USD (national)

CLIMATE UNCERTAINTY

Limited | Partial | Considerable

COUNTRY 2010 2030 2010 2030 2010 2030

Jamaica  New Zealand
Japan    Nicaragua
Jordan   Niger
Kenya    Nigeria
Kiribati  North Korea
Kuwait    Oman
Laos      Palau
Latvia    Panama
Lebanon   Papua New Guinea
Lesotho   Paraguay
Liberia   Peru
Libya     Philippines
Lithuania  Poland
Luxembourg Portugal
Macedonia  Qatar
Madagascar Romania
Malawi    Rwanda
Malaysia  Saint Lucia
Mauritania Saint Vincent
Mauritius  Sao Tome and Principe
Mexico    Saudi Arabia
Micronesia Senegal
Moldova   Seychelles
Morocco   Sierra Leone
Mozambique Singapore
Namibia   Slovakia
Netherlands Slovenia
Somalia   Solomon Islands
South Africa South Korea
South Korea

Additional persons affected due to climate change - yearly average